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Scientists Hunt for A Seeming Paradox: A Magnet With Only One Pole

For centuries, physicists have hunted for magnetic monopoles to help put together their theory of everything. They may be closer than ever.

By Adam Hadhazy|Tuesday, November 13, 2018

As a child, James Pinfold adored magnets. He recalls marveling at the invisible force that clacked the metallic objects together or hurled them apart. Out of curiosity, he once sawed a bar magnet in half, trying to separate its north and south poles. Like anyone else who's ever made the attempt, Pinfold instead just ended up with a pair of smaller two-poled magnets. "I thought, 'That's amazing,' " says Pinfold, now a physicist at the University of Alberta. "Why could there not be separate poles?"

It's a question he's never stopped asking. Pinfold is now the leader of an experiment looking for theoretical particles with single magnetic charges — a north without a south, and vice versa. Called magnetic monopoles, they seem perfectly possible, even inevitable, in a host of theories physicists have proposed for unifying nature's fundamental forces.

Yet the pesky particles have eluded science's grasp for decades. Researchers have looked to the skies, in seawater and in ice for them. They've picked through rock samples from the Arctic and Antarctica, searched in meteorites and moon dust, and sought traces of them in ores dating back nearly a billion years. In the history of science, arguably nothing has been searched for more, through both space and time, than the magnetic monopole. And still, nothing.

But physicists have no intention of throwing in the towel. Pinfold's experiment, at the $4 billion Large Hadron Collider (LHC), is sifting through subatomic shrapnel for monopolar signatures, and scientists are also keeping their eyes peeled for cosmic monopoles falling from space. There's even a chance we've already spotted the darn things.

Why all the fuss? Magnetic monopoles may just help break the current logjam in particle physics. A framework known as the Standard Model, built up over decades, describes three of the four fundamental forces of nature and their attendant particles in the precise language of quantum mechanics. It's among the most successful theories in all of science, but remains hopelessly incomplete. It fails to accommodate the force of gravity, for instance. Nor can it explain the bugbear of dark matter, a mysterious substance outnumbering regular matter 5 to 1.

Magnetic monopoles, a brand-new type of particle, could show the way forward. "A monopole would take us well beyond the current Standard Model," says Pinfold. Monopoles could reveal how to combine the three standard forces, allowing scientists to move a step closer toward a so-called theory of everything, putting all of physics under one roof. Humankind could at last understand the entirety of the universe's behavior.

But first: the hunt.

A Persistent Problem

The quandary of the elusive magnetic monopole goes back more than 150 years. In the 1860s, Scottish mathematical physicist James Clerk Maxwell devised equations joining at the hip the phenomena of magnetism and electricity. They were both expressions of the same fundamental force, fittingly named electromagnetism.

In his equations, Maxwell included the already-known positive and negative charges for electricity. These opposite charges readily split apart: Rub a balloon on your hair so it stands up from gaining extra static charge, and you've done it. But because magnetism always seemed to manifest as twofers — those conjoined north and south poles known as dipoles — he did not include individual magnetic charges in the theory.

Maxwell's paradigm has worked just fine without magnetic charges; his insights made possible most modern technology, from electrical power generation to wireless communications to computers.

Theoretical developments in the 20th century, though, squarely made the case for monopoles. In 1931, English theoretical physicist Paul Dirac showed that quantum mechanics permitted such a particle, and by the 1970s, monopoles emerged as a consequence of Grand Unified Theory.

This framework weds three of nature's fundamental forces — the strong, the weak and the electromagnetic — into a single entity. But that unification is only possible in the intensely hot, energetic unfolding of the universe's birth, the Big Bang. Separately, string theory, which proposes that forces and particles all arise from the vibrations of tiny stringlike units, gave monopoles yet another thumbs-up.

With all the circumstantial theoretical evidence for monopoles, one of the foremost string theorists in the world, Joseph Polchinski of the University of California, Santa Barbara, commented in 2002 that their existence is "one of the safest bets that one can make about physics not yet seen." Sixteen years later, before he died in February 2018, he still stood by that statement. "Whenever you go to a fully unified theory of physics," he said, "you always find that magnetic monopoles come along."

The basic profile of monopoles depicts them as elementary particles carrying magnetic charge. They would be analogous to the particles that carry electric charge, electrons and quarks, which constitute the matter around us.

Monopoles would act familiarly, too: The same charges would repel each other, while opposite charges would attract. The particles would likely possess considerable mass. Scientists are confident they would interact with everyday matter in predictable — and ultimately detectable — ways.

"At a very basic level, that's a reason why we think monopoles are worth looking for," says theoretical physicist Arttu Rajantie. "We really know what they would behave like."

Maybe Monopoles?

While physicists are hard at work hunting magnetic monopoles, decades-old findings suggest we may already have stumbled upon them.

On Feb. 14, 1982, Stanford University researchers detected a characteristic electric current on a superconducting loop, only thought possible from a magnetic monopole. And three years later at Imperial College London, another unexplained current popped up that also perfectly matched theoretical predictions. Since no other detectors have reported such events, many scientists dismiss the signals as unexplained instrument errors or background noise. But if that were the case, argues physicist James Pinfold, surely other spurious, and likely explainable, detections would have occurred over the years. "It is indeed very difficult to have a problem that exactly mimics the signal from a monopole," he says.

Even further back, in 1973, a University of California, Berkeley-led team launched a balloon outfitted with a stack of detectors, including plastic sheets like the LHC's MoEDAL detector uses. Near Sioux City, Iowa, something heavy and tantalizingly monopole-esque zipped through the airborne detector — though it was more likely the nucleus of a heavy element that had come screaming in from deep space as a cosmic ray. Again, a lack of an encore has left scientists frustrated, but intrigued.

MoEDAL Detector

Rajantie's first name, Arttu, is pronounced like the *Star Wars* character R2-D2; a toy of the lovably squat droid sits atop his office computer at the Imperial College London. From there, Rajantie makes the occasional trip to the LHC in Geneva, Switzerland, where he's part of Pinfold's project, hot on the trail of magnetic monopoles. Dubbed MoEDAL (pronounced like "medal," for the Monopole and Exotics Detector at the LHC), the collaboration has brought together about 70 people hailing

from four continents. The MoEDAL instrument began gathering data in 2015 and will carry on through the LHC's current run, ending this December, and likely through the next from 2020 to 2022.

A visitor to the LHC might not look twice at MoEDAL; it resembles a set of silver-metallic storage lockers. MoEDAL shares an underground cavern with part of the big-budget, house-sized experiment dubbed the LHCb. This project detects "beauty" quarks, short-lived particles that spew out of head-on collisions between twin beams of protons traveling just within a whisker of the speed of light. The beams shoot through two pipes running the roughly 17-mile length of the ring-shaped LHC, and the proton pyrotechnics take place right inside MoEDAL's cavern.

MoEDAL's lockerlike detectors wrap around that collision point, awaiting any magnetic monopoles that might leave the fray. The particle would plow through thin sheets of plastic in MoEDAL's compartments, leaving permanent, ultrathin trails of destruction. "MoEDAL is like a giant camera," says Pinfold, and the plastic sheets "are like its film." If his team spots an aligned set of tiny holes in the film, pointing back to the LHC's proton collision, Pinfold and crew will be reaching for the champagne.

"MoEDAL detects only new physics," he says. "No known Standard Model particle can do that in our plastic." The detector should therefore spot more than just monopoles, a proper jungle of particle beasties. "Just one detection event is enough to establish that something wonderful has happened," says Pinfold.

A second type of detector within MoEDAL, made of aluminum, would do one better in the monopole hunt by actually ensnaring the renegade particle. "If a magnetic monopole flies through the aluminum, it will slow down and become trapped," says Rajantie. Researchers would learn of its presence by passing the aluminum through a superconducting loop — a device that picks up weak magnetic fields. An ordinary dipole magnet creates two electrical currents in the loop that effectively cancel each other out; a solo pole, however, would trigger a sustained electric current. "There's no way to fake that signal of a trapped monopole," says Pinfold.

Their monopole trap thus set, now all the researchers have to do is watch and wait, fingers crossed.

All-natural Monopoles

On the other side of the world, scientists are taking a different approach. Instead of hunting man-made monopoles wrought by artificial particle collisions, these physicists are seeking natural, cosmic monopoles, originally forged in the furnace of the Big Bang and falling to Earth from space. These monopoles can range in size, from superheavies to lighter varieties, and they also move at radically different speeds, with the fastest whipped around by magnetic fields to travel at near light speed.

The fleet-footed monopoles are the targets of the Pierre Auger Observatory. Sprawling across a plain below the Andes Mountains in western Argentina, Auger chiefly spots cosmic rays, incredibly energetic particles zipping through the cosmos. Upon entering our airspace, cosmic rays first obliterate some hapless molecule in Earth's atmosphere. The debris from the crash then initiates a cascading chain reaction of billions of particles, known as an air shower, that blazes toward the ground and emits characteristic ultraviolet light.

With any luck, Auger's ultraviolet-tuned telescopes could also detect a falling cosmic monopole. The difference is easy to spot: A cosmic ray peaks early on in ultraviolet energy, then diminishes as its air shower dies out. A hardier monopole would instead keep cranking out energy as it fell.

"Everything is based on the fact that monopoles have interactions with a material in a detector," says Paolo Privitera, an astrophysicist at the University of Chicago and a principal investigator for Auger. In MoEDAL's case, the detector is plastics and aluminum. "In our case," he says, "it's the air, the atmosphere."

So far, no monopoles have been detected in the skies over Auger. But the odds of catching them should go way up by using the observatory's primary cosmic ray detectors: a horde of nearly 1,700 water-filled tanks scattered across 1,200 square miles, just a shade smaller than the state of Rhode Island. The highly energetic particles in a cosmic ray's air shower plow through the water faster than light can. (Light only moves at its indomitable top speed in the vacuum of space.) As they do so, the particles give off detectable flashes of light called Cherenkov radiation, akin to an optical sonic boom. Monopole particle showers should also produce the effect, making the water tanks an equally useful tool to spot them. Auger researchers are currently working out exactly how to differentiate them from cosmic rays.

Another observatory, the IceCube Neutrino Observatory at the South Pole, uses neither air nor liquid water, but ice as its monopole dragnet. The project's scientists have sunk scores of cables studded with thousands of sensors into a cubic quarter-mile of pristine Antarctic ice. The sensors' primary duty is to expose ghostly particles called neutrinos, which interact with ice molecules to create fast-moving charged particles that also produce Cherenkov light.

Fast-moving monopoles likewise pump out this light, and so do the comparatively massive, slowpoke monopoles — but for a different reason. These monopoles, borne of the early Grand Unified era of the Big Bang when three of the fundamental forces were joined as one, would possess a vestige of the extreme energy density where the differences between Standard Model particles and forces disappear. "The Grand Unified monopole contains in its tiny heart a little bit of the Big Bang, when all the forces were equal," says Pinfold. When a proton in ice is exposed to this core of a monopole, where elementary particles' differences disappear, the proton decays, with its constituent quarks transforming into other particle types including positrons, which can generate detectable Cherenkov light.

As of 2015, when they issued their most recent major report on the topic, researchers hadn't found any monopoles with IceCube, based on two years' worth of data. But again, patiently waiting could yet pay off.

A Magnetic Future

If magnetic monopoles ever do show up in Earth's vicinity, or the detritus of particle collisions, we will know it. And should someone, somewhere, indeed manage to unambiguously nab one of the little rascals, then the real fun begins. Wrangling monopoles could be easy, bending the particles to our will just by applying common electromagnetic fields. Monopoles might flow as magnetic, instead of electric currents, paving the way for "magnetronic" technologies involving "magnetricity," perhaps in ultra-compact data storage or totally reimagined computer architectures.

As for science experiments, working with a new particle could finally deliver on those Grand Unified Theories and even theories of everything. Getting to that new realm of physics would likely require the brute thrill of smashing monopoles' heads together. "If we can find them," Rajantie says, "ultimately what we particle physicists would like to do is have a collider where we collide monopoles with other things and see what comes out." Who knows, maybe the LHC could give way to an LMC — a Large Monopole Collider.

And finally, Pinfold and those like him who have wondered why magnets cannot splice into solitary north or south poles would have an answer.

"The magnetic monopole runs through the development of modern theories of the universe like a golden thread," says Pinfold. "If we do see something, it will be a very big deal."

Funky New Physics

Although the magnetic monopole is the big fish MoEDAL seeks, the experiment could haul in plenty of interesting bycatch. Here are some other exotic phenomena that could leave anomalous trails in MoEDAL's detection system.

Black hole remnants. It's possible the particle smashups in the Large Hadron Collider could create microscopic black holes. (Don't worry, these motes can't gobble up the planet.) The late Stephen Hawking thought the itty-bitty objects would rapidly lose mass and evaporate, but perhaps leftover particles would persist. These remnants would help bridge

incompatible theories of the cosmos at its largest and smallest scales, as well as possibly constitute a sizable portion of the presently unaccounted-for dark matter.

Strangelets. Protons and neutrons in atoms of everyday matter are composed of "up" and "down" quarks. So-called strange matter, though, throws heavier "strange" quarks into this mix, creating particles called strangelets. This hypothetical material might have a lower energy state than regular matter, making it even more stable. The dense remains of exploded, titanic stars — currently known as neutron stars — could be made of this stuff, begging an even cooler nomenclature: strange stars.

Sparticles. Supersymmetry proposes that each known elementary particle has a partner particle. For instance, quarks would be complemented by squarks; the electron, by the selectron. These sparticles could exist across extra dimensions of space we're oblivious to. If so, that would explain why the force of gravity is so wimpy compared with nature's other forces — it mostly resides in a realm outside our own.

Physicists Finally Made The One-Poled Magnet They've Been Missing For 80 Years

ANDY KIERSZ

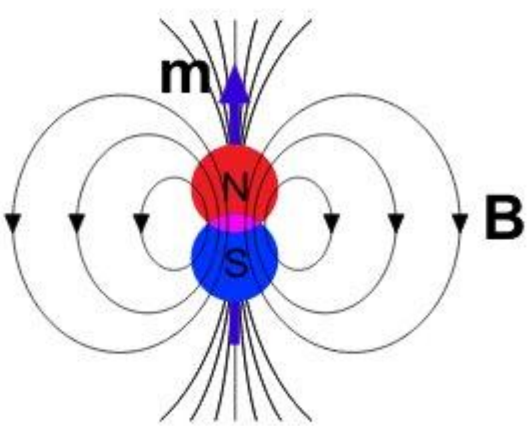
80 years after they were first theorized, scientists have just created an artificial magnetic monopole.

Monopoles were first conceived in their modern form more than 80 years ago by Paul Dirac, one of the founders of quantum mechanics.

This discovery has some powerful implications for physics.

Magnets — how do they work?

Every magnet that we have ever observed is a dipole — it has both a north and south pole. If we draw magnetic field lines around a magnet, we always see the lines curve around, joining the two poles.



Wikimedia Commons **A regular, two-poled magnet.**

If you cut this magnet in half, you are not left with one north magnet and one south magnet, but instead two new double-poled magnets.

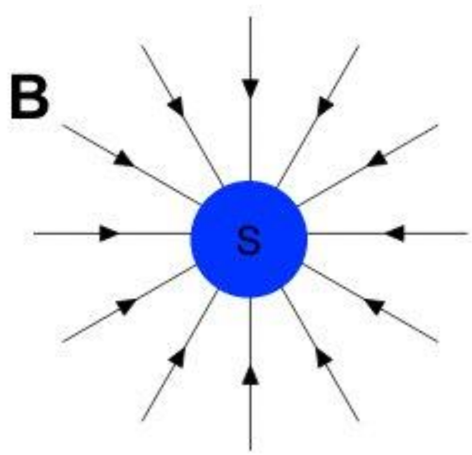
This goes on and on to the atomic level — you can keep cutting the magnet apart, but each part will still have two poles. Even a single spinning electron has both a north pole and a south pole.

That is how every magnet we have ever seen or experienced works.

Until now.

Now, researchers at Amherst College in Massachusetts and Aalto University in Finland have created a mysterious Dirac monopole in the lab.

The monopole acts as a single-point source for a magnetic field. The magnetic field lines stretch out from the monopole in all directions, without the looping back seen in a normal dipole.



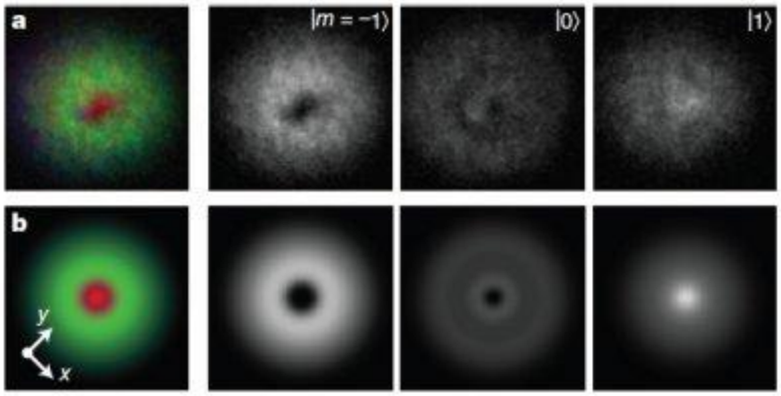
Wikimedia Commons **The mysterious magnetic monopole.**

Before the latest finding, researchers searched high and low but never found a magnetic monopole in nature.

Monopoles for other physical forces are ubiquitous in nature — electric monopoles exist all over the place. The protons and electrons that are some of the basic building blocks of matter generate electric fields centered on themselves without a corresponding opposite pole.

Finding the elusive monopole

The researchers used some high-tech lab work to create their artificial magnetic monopole, which they published Jan. 30 in the journal Nature.



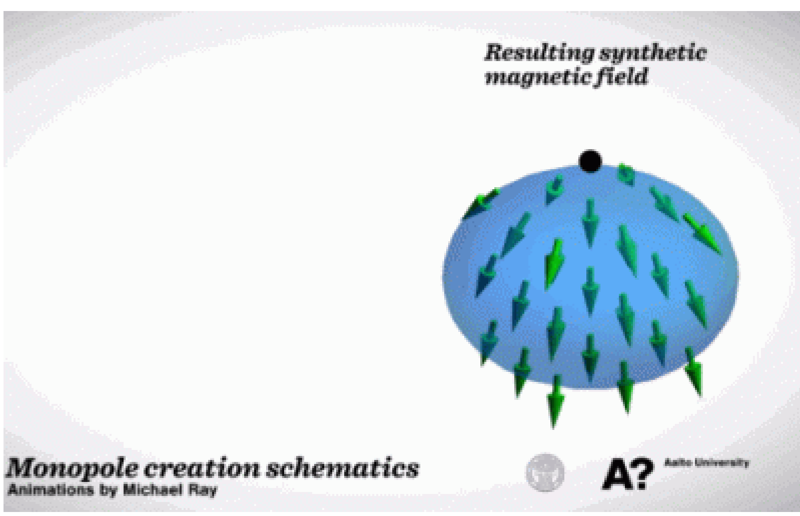
M.W. Ray et. al., Nature, 2014 **The top row shows the scientists' experimental results. The bottom row shows their mathematical predictions. The close similarity between the two suggests that a monopole was formed. The vortex can be seen as the dark spot in the center of the condensate.**

Their first step was making a Bose-Einstein Condensate — a small cloud of atoms cooled to a few billionths of a degree above absolute zero.

The cooling process involves shooting atoms in a cold gas with lasers, sapping the atoms of their momentum, and then carefully manipulating the atoms with magnetic fields to slow them down even further.

At this temperature, the atoms are almost stationary, and weird quantum effects start to happen. The atoms begin acting very strange and form a new kind of matter — different from the solids, liquids, and gasses we are used to.

The researchers then carefully applied finely tuned magnetic fields to the strange matter, forming tiny tornado-like vortexes in the fluid.



Aalto University

This animation, taken from a YouTube video posted by the researchers at Aalto University, shows how the monopole is made. By carefully balancing out external magnetic fields to move a point at the base of a vortex into the middle of the condensate, the condensate itself begins to emit an outward pointing monopole-style magnetic field.

The researchers call this the "hedgehog configuration."

The mathematics that describe the theoretical behaviour of the Dirac magnetic monopole very nicely line up with what this matter looks like in the hedgehog condition, the researchers said.

What's it all mean?

Being able to generate a monopole like this in a lab has some serious implications for physics. When Dirac first hypothesized the monopole in 1931, he realised that the existence of such a thing in nature would confirm a fundamental idea in modern physics — the quantum nature of electricity. This means that electric charge can only exist as whole number multiples of some fundamental basic charge — you can't have something with one half the electric charge of an electron.

Various theories of the Big Bang suggest that in the unfathomably high temperatures of the very early universe, exotic magnetic monopole particles should have formed. Some of these particles should still exist today, although they would likely be extremely rare. Finding a natural monopole would help us better understand the conditions of the newborn universe.

Scientists have searched for evidence of these naturally occurring monopoles in places ranging from Antarctic ice to lunar rocks. To date, these hunts for naturally occurring monopoles have all failed.

Making a synthetic monopole indicates that these kinds of magnetic fields can exist without violating the laws of physics, leaving open the door for a natural monopole. Future research into the properties of synthetic monopoles could lead to new insights into how to find these strange particles in nature.

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